Textile Dyes-Polluted Water Detection using Ultrasonic Waves Propagation Method

Darmawan Hidayat*, Aulia Ramadhita, Nendi Suhendi Syafei, Setianto Setianto, and Arjon Turnip

***Abstract*— Water pollution is an environmentally problematic issue, mainly in developing countries. It requires a system measurement to detect the time and location when and where the water pollution occurs. This paper reports the utilization of ultrasonic waves for the detection of water pollution. A 1-MHz ultrasonic wave was propagated through the aqueous liquid mixture medium, with the pollutant types of textile dyes, washing detergent, and glycerin, respectively. The phase velocity and acoustic attenuation through medium-propagated ultrasonic waves were measured and correlated to the concentration and types of pollutant substances. The measurement results showed that the propagation velocity was 1450–1717, 1450– 1687, and 1450 –1570 m/s when concentration varied from 0–25 wt%, in the pollutants water samples of textile dyes, washing detergent, and glycerin, respectively. It observed that the phase velocity increased linearly with increasing concentration of pollutant, indicated by R^2 values of 0.99432, 0.98771, and 0.99384 for pollutant samples of textile dyes, washing detergent, and glycerin, respectively. In comparison, acoustic attenuation shows a lower correlation to the concentration of pollutants. In conclusion, the phase velocity of the ultrasonic wave has high reliability for detecting water pollution.**

***Index Terms*— polluted water, hardware engineering, ultrasonic waves, phase velocity, acoustic attenuation**

I. INTRODUCTION

WATER pollution occurs when harmful substances (often chemicals or microorganisms) contaminate a stream, river, lake, ocean, aquifer, or other body of water. It deteriorates water quality and causes it to be toxic to humans or the environment [1]. Water pollution has become a major problem, particularly in developing countries that foster industrial development for increasing national economic growth [2]. However, industrial processes involve many harmful chemical substances and eventually result in environmentally hazardous liquid waste [3]. Despite government regulations obliging industries to carry out waste treatment, there are many cases observed that liquid waste is directly disposed of in a stream or river without any proper waste treatment [4].

This is mainly caused by the difficulties in the on-site waste treatment supervision due to a large number of operated industries, the large area of water pollution coverage, technical problems, the measurement system, social problems, and so on [4]. For instance, the Citarum River, the longest and the largest river located in West Java province, Indonesia is 270 km long and extensively extends from Wayang Mountain (Bandung Region) to Muara Gembong (Bekasi Region). There are many industries built located nearby the Citarum River bank. In many cases, it is problematic to determine and prove scientifically when the time and which industry disposing of the untreated waste to the river. This issue could be a serious dispute between the government as the regulator, the industries side, and the affected societies. Therefore, it necessitates to develop an in-situ and real-time measurement system of the polluted river water to address this issue. For this purpose, this could be realized by an internet of things (IoT)-based multinode measurement system connected to the internet cloud (Fig. 1) [5]. By this method, water pollution occurrences could be detected and monitored, and the information sent to the stakeholders for law enforcement purposes.

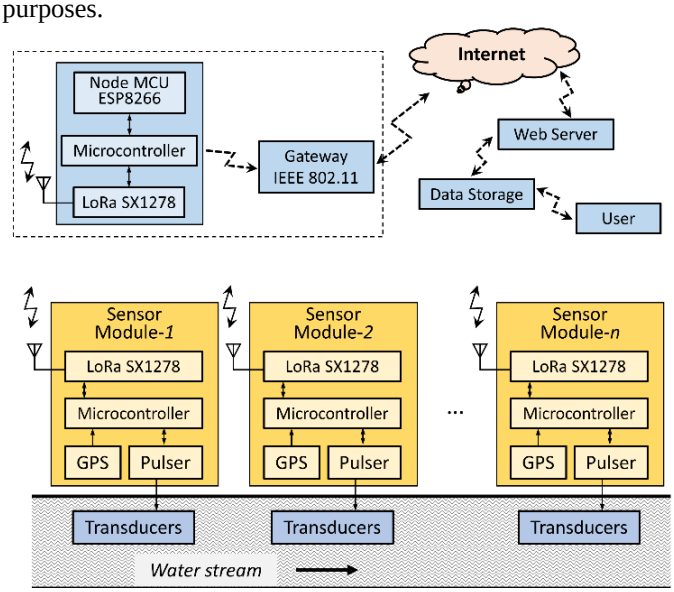

Fig. 1. IoT-based water pollution detection tophology using ultrasonic wave

Several methods have been developed in recent years to

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detect water pollution. These include using bio detectors such as fish gills and bacteria as biomarkers for pollutants detection [5,6] and using commercially available and wet chemical sensors for mobile measurement [7]. Various methods employing ultrasonic waves to detect water pollution and as well as physical quantities measurement have been investigated by other researchers. It is due to the advantages of ultrasonic wave capabilities, that is high penetration, low cost, low power, safety, and readily available [7,8,9,10,11]. It was reported the utilization of the ultrasonic different transmission velocity for the detection of pollutants [8], measuring sound attenuation for estimating impurities in water [9] and measuring the time delay of ultrasonic propagation for high-temperature measurement [10]. It was also reported the use of ultrasonic for water droplet generation, and water remediation in the degradation of Microcystins-polluted water [12,13]. However, to the best of the authors' knowledge, no research has yet been carried out to investigate the phase velocity and acoustic attenuation of propagation ultrasonic waves to evaluate the polluted water purposes. Therefore, it necessitates to development of an in-situ and real-time measurement system of the polluted river water to address this issue.

This paper reports the application of ultrasonic waves for the detection of water that is polluted by textile dyes, washing detergent, and glycerin. The correlation between the concentration and type of pollutants in water samples with the ultrasonic wave parameters such as the phase velocity and attenuation were evaluated.

II. EXPERIMENTAL SETUP

A. Sample Preparation

The total volume of the aqueous sample was 100 mL using a mixture of distilled water and a pollutant substance. Three pollutant types were used, i.e. textile dyes, washing detergent, and glycerin. The mixture of distilled water and a pollutant substance was rigorously mixed for five minutes. Each water-pollutant mixture had a weight concentration that varied from 0–25 wt%.

B. Ultrasonic Parameters Measurement

The acoustic properties including the phase velocity and the power attenuation of the polluted-water samples were evaluated by propagating a 1-MHz ultrasonic wave through the sample at a transmission mode of propagation as depicted in Fig. 2.a. Both transmitter and receiver transducers were identical, immersed-transducer type and having a center frequency of 1 MHz. The transducers were placed at a distance *d* of 11.57 mm in a cylindrical test cell and immersed in the liquid mixture samples.

The transmitter transducer was excited by a 2-cycle square wave bipolar pulse, a width of 0.5 ms, and bipolar pulse voltages of +30 V and -30 V (Fig. 2.b). The propagated ultrasonic wave is received by the receiver transducer. It is subsequently amplified, displayed, and recorded by a high-speed digital storage oscilloscope (DSO) series GW-Instek GDS-2104A for further offline data analysis [14].

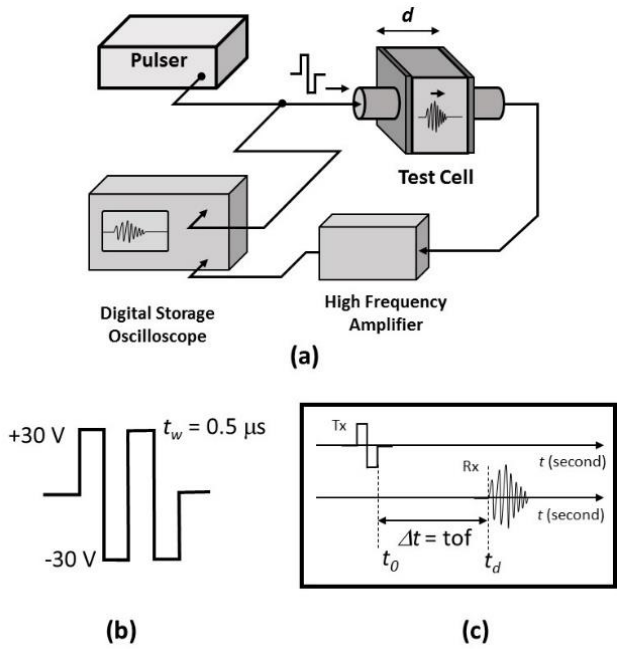

Fig. 2. Experimental setup of the acoustic parameters measurement of the samples with (a) the apparatus arrangement, (b) the transmitter excitation signal and (c) time points of tof measurement

The phase velocity and attenuation were calculated by measuring the time of flight (tof) and transmitted-received signal amplitudes, respectively. The tof measurement was carried out by measuring the t_0 and t_d times difference (Fig. 2.c). The value of t_0 is determined by placing both transducers at d = 0 mm [10].

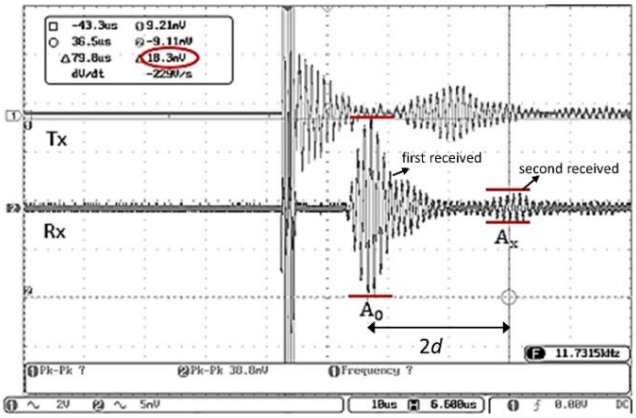

Fig. 3. The measurement of acoustic attenuation based on received signal the amplitudes A_0 and A_x

Fig. 3 shows the signal received by the receiver transducer. It is observed two sequencing oscillation signals with peak-to-peak amplitudes of, A_0 and A_x, respectively. The original ultrasonic wave generated by the transmitter propagated to the sample medium and was received by the receiver transducer as A_0. This A_0 signal is reflected and propagated toward the transmitter. As the A_0 signal encounters the transmitter transducer, it is reflected and propagated through the medium and received by the receiver transducer as the second signal

A_x. Hence, the signal completed the propagation at a 2d distance with initial and final amplitudes A_0 and A_x, respectively. The sound velocity, c, and attenuation coefficient, α is calculated using (1) and (2) [15], respectively.

$$c = \frac{d}{t_d - t_0} = \frac{d}{tof} \quad (1)$$

$$\alpha = -\frac{1}{2d} \ln \frac{A_x}{A_0} \quad (2)$$

III. RESULTS AND DISCUSSIONS

Fig. 4 shows the water samples polluted by textile dyes and washing detergent. The textile dye-polluted water samples were dark blue in color and odorless (Fig. 4.a), while the washing detergent-polluted water sample was clear transparent and odored. The glycerin water samples were clear transparent and odorless. These samples were chosen with consideration for the detection of water pollution in case of the pollutant is visually clear and odorless such that the pollutants were not detected by human visual or smell.

The phase velocity and acoustic attenuation of propagated ultrasonic are the parameters of interest in the measurement because they characterized the physicochemical quantity of the propagating medium. It was reported that the phase velocity had a high correlation to the mixture concentration of liquid mixtures [16,17,18]. The change in the concentration of sample pollutant concentration varies the physicochemical properties of the samples and hence determined the phase velocity and attenuation values. All measurement results derived are summarized in Table 1. To evaluate the measurement sensitivity with regard to the pollutant concentration, the change variation of pollutant concentration, Δw was varied at 0.2, 1, and 5 wt% in the range of 0–1, 1–10, and 10–25 wt%, respectively.

Fig. 5 shows the measured velocity of the samples with respect to the pollutant concentration. As seen in Fig. 5, the phase velocity linearly increases with increasing pollutants concentration. It is proportional to the concentration. The textile dyes, washing detergent, and glycerin provide an evident strong correlation between the phase velocity and the concentration, indicated by R^2 values of 0,98771, 0,99432, and 0.98771, respectively. At a particular value of pollutant concentration, it is also found that the velocity of each polluted sample has a distinctive value. For instance, at a concentration of 15 wt%, the phase velocity of washing detergent-, textile dyes- and glycerin-polluted samples are 1607, 1576, and 1516 m/s, respectively. The increase of pollutant mixture concentration results in the density of the mixture. The propagation velocity of ultrasonic waves is proportional to the density. Thus, it can be understood that the velocity increased with the increasing concentration of pollutant liquid mixture.

The results depicted in Fig. 5 show that the phase velocity is highly correlated to the pollutant concentration, the textile dyes, washing detergent, and glycerin in this case. These results provide evidence that the phase velocity parameter has the capability for measuring and distinguishing the pollutant quantity and types that dissolved in the water.

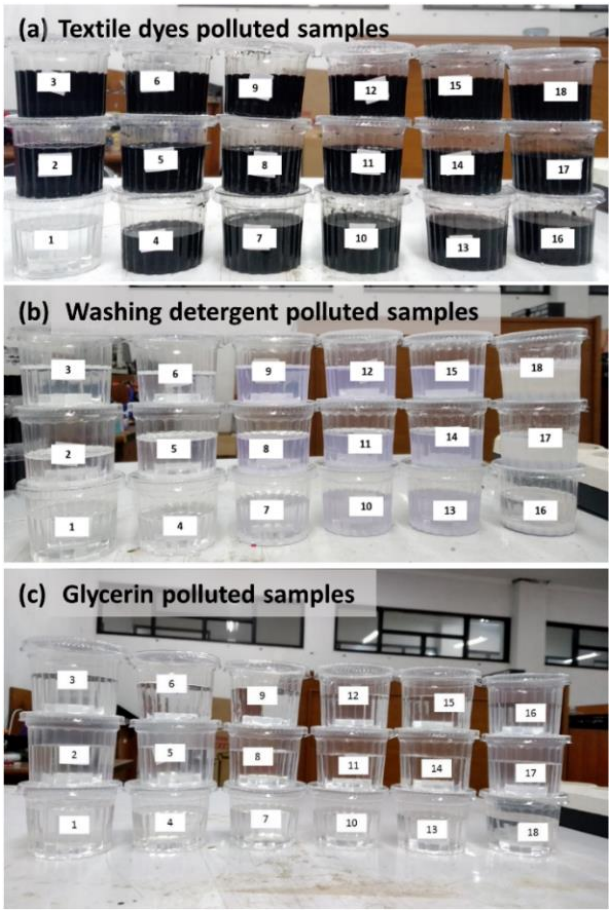

Fig. 4. Water samples with pollutant types of (a) textile dyes, (b) washing detergent, and (c) glycerin at a concentration variation of 0 – 25 wt%

TABLE 1. THE MEASURED PHASE VELOCITY AND ACOUSTIC ATTENUATION OF ULTRASONIC WAVES PROPAGATED IN THE POLLUTED WATER WITH RESPECT TO THE POLLUTANT TYPES AND CONCENTRATION

w (wt%)	Washing detergent		Textile Dyes		Glycerin	
	c (m/s)	a (Np/m)	c (m/s)	a (Np/m)	c (m/s)	a (Np/m)
0	1450	0.01155	1450	0.01143	1450	0.00920
0.2	1455	0.01136	1459	0.01090	1454	0.00922
0.4	1457	0.01136	1465	0.01113	1455	0.00931
0.6	1459	0.01140	1472	0.01082	1457	0.00912
0.8	1463	0.01140	1474	0.01086	1461	0.00922
1	1470	0.01127	1480	0.01082	1463	0.00914
2	1478	0.01158	1483	0.01094	1465	0.00895
3	1489	0.01152	1487	0.01094	1468	0.00901
4	1493	0.01192	1495	0.01117	1470	0.00914
5	1497	0.01195	1497	0.01139	1478	0.00900
6	1510	0.01179	1507	0.01147	1481	0.00900
7	1520	0.01202	1520	0.01151	1485	0.00906
8	1520	0.01179	1532	0.01162	1489	0.00898
9	1545	0.01154	1547	0.01151	1493	0.00912
10	1547	0.01151	1549	0.01162	1497	0.00899
15	1607	0.01203	1576	0.01177	1516	0.00915
20	1655	0.01211	1630	0.01214	1541	0.00937
25	1717	0.01243	1687	0.01247	1570	0.00980

In order to observe the precision of measurement, the pollutant concentration varied with a change, Δw of 0.2, 1.0, and 5.0 wt% in the range of 0–1.0 wt%, 1.0–10.0 wt%, and

10.0 – 25.0 wt%, respectively (see Table 1). In the range of the smallest value Δw of 0.2 wt% (concentration range of 0–1 wt%), it was observed that the phase velocity in water polluted by pollutants type of washing detergent, textile dyes, and glycerin varied respectively in a range of 1450–1470, 1450–1480 and 1450–1463 m/s. From the measurement results, the measurement precision up to 0.2 wt% was evident.

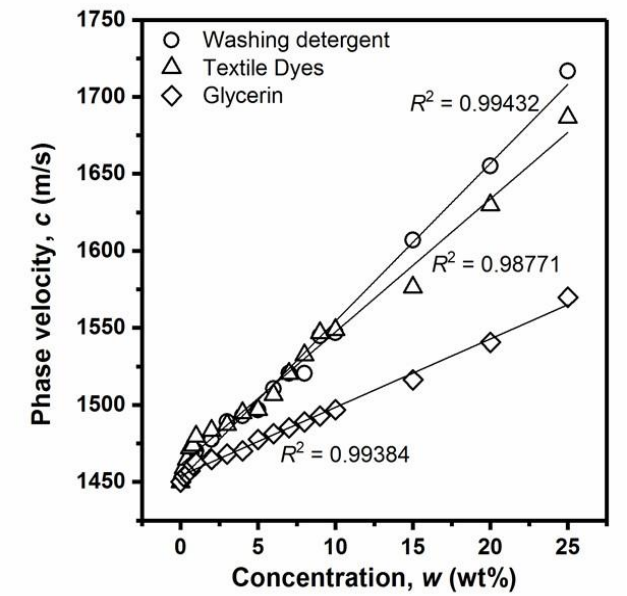

Fig. 5. Ultrasonic waves phase velocity with respect to the pollutants substance concentration types of textile dyes, washing detergent and glycerin

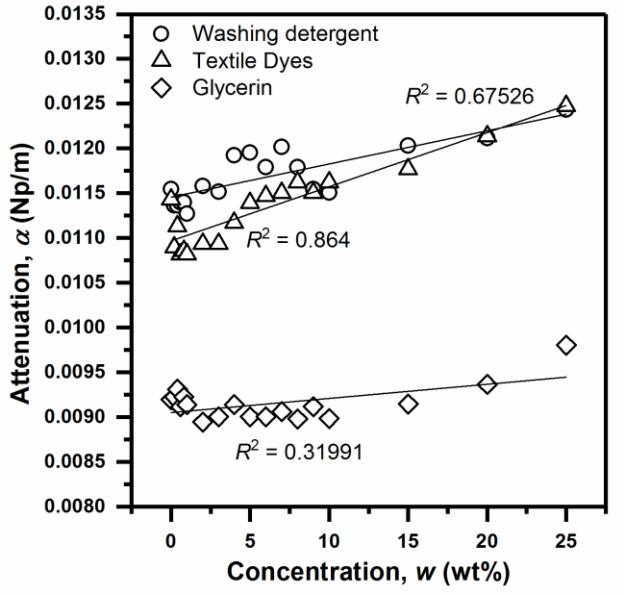

Fig. 6. Ultrasonic waves phase attenuation with respect to the pollutants substance concentration types of textile dyes, washing detergent and glycerin

In addition to phase velocity, acoustic attenuation became a quantity of interest in the evaluation of various liquid mixtures, such as gasoline-organic compounds [16], diesel-biodiesel blends [17], biofuel-ethanol adulteration [18], and liquid density [19]. Instead of liquid mixtures, attenuation was employed to characterize the breast tissue [20]. They found that attenuation has a reliable correlation to the assessed quantities. Therefore, it is important to evaluate the correlation of attenuation with the concentration and pollutant types of the samples. From the measurement results shown in Fig. 6, the acoustic attenuation increased with the increasing concentration of pollutants. Attenuation-to-concentration relationships show more scattered distribution than that velocity. This result is in accordance with results reported on liquid mixture evaluations [16, 17].

It is known that the liquid mixture density increases when the pollutant concentration increased. This results in higher acoustic absorption by the liquid mixtures. This can be understood that the increasing absorption loss in the propagating medium eventually causes an increase in the attenuation coefficient of the liquid mixture [19, 21].

When it was correlated to the concentration with a linear function, it showed a smaller value R^2 (0.864, 0.6753, and 0.3199) indicating a lower correlation between attenuation and concentration. Similarly, the smallest Δw of 0.2 wt% in the range of 0–1.0 wt% provided different attenuation values implying the precision of measurement could be achieved up to 0.2 wt%. Likewise, at an equal concentration, the attenuation of textile dyes and washing detergent samples exhibited different values. However, this result suggested that the attenuation had lower reliability as a measured parameter for distinguishing the pollutant types.

IV. CONCLUSIONS

The phase velocity and acoustic attenuation measurements of textile dyes and washing detergent water have been carried out and demonstrated. The measurement results showed that the phase velocity was 1450–1717, 1450–1687, and 1450–1570 m/s when concentration varied from 0–5 wt%, in the pollutants water samples of textile dyes, washing detergent, and glycerin, respectively. The phase velocity has a strong correlation to the concentration and types of pollutants, indicated by R^2 values of 0.9943, 0.9871, and 0.99384 for pollutant substances of washing detergent, textile dyes, and glycerin, respectively. These R^2 values are larger than that of the attenuation measurement. In summary, the results of this work suggest that ultrasonic waves have potential applications in the detection of textile dyes and washing detergent-polluted water.

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